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**Progress and Future Directions in Chemical Methods
for the Control of Scale at the Salton Sea Geothermal Field**

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**This paper was prepared for presentation at the
Workshop on Scale Control and Related Topics
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Progress and Future Directions in Chemical Methods
for the Control of Scale at the Salton Sea Geothermal Field

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Using a pilot-sized brine handling system operated from Magmamax No. 1 well at the Salton Sea Geothermal Field, a series of field tests have been conducted in which various chemical compounds were examined as possible scale control agents. Control of silica and silicate scales by means of chemical treatment has been moderately successful in other applications, but at the inception of our study virtually no knowledge existed of the types of compounds that would interact with silica under the severe geothermal conditions of high temperature, high solution ionic strength, and high fluid shear rates. Brine acidification had been shown previously to be an effective method of scale abatement,^{1,2} but its several disadvantages have recently redirected our attention toward the alternative use of organic compounds. Subsequent studies³ revealed that proprietary additive formulations recommended for conventional industrial water treatment purposes were ineffective as geothermal antiscalants.

To continue our investigation of inhibitors for siliceous scales, we have sought substances that would act to stabilize the colloidal silica as it forms from supersaturated solution. Effective stabilization would prevent the growth of suspended particles by aggregation and decrease the rate of deposition of particles on substrates. Our approach in screening compounds for subsequent scaling tests was to inject the additive into the brine at nearly wellhead temperatures, so that it accompanies the brine as it is flashed; withdraw samples of brine at lower temperatures; and then measure the effect of the additive on the rate of precipitation of silica from the brine at its effluent temperature of 90°C. The best precipitation inhibitors were then selected and subjected to measurements of their effects on the formation of scale at three temperatures: 220, 125 and 90°C. These studies have been summarized in a series of publications.⁴⁻⁹

The large number of compounds evaluated (>120) have suggested some general aspects of the mechanism of the interactions between organic compounds and silica in geothermal brine. In addition, the variations in

brine chemistry encountered in the course of testing have led to information on the effect of this parameter on scale deposition. The salient features are the following: (1) Brine salinity plays a major role in determining the rates of silica precipitation and scaling; the higher the salinity, the greater the rate of scaling. (2) Organic compounds that interact with silica fall into two main classes: compounds containing polymeric chains of the oxyethylene moiety, $-\text{CH}_2\text{CH}_2\text{O}-$, and nitrogen-containing compounds that function as cations in solution. (3) The cationic polymers (such as the polyethylene imines and polyaminoethylenes), although commonly used as flocculants in other applications, function as silica colloid stabilizers in the hypersaline brine if they are added at the proper time. (4) It appears possible to combine the functions of silica dispersion and steel corrosion inhibition in a single molecule, thereby enhancing the scale retardation and general utility of the compound. (5) Although there is no direct evidence of the mechanism of interaction of the organic compounds with the colloidal silica, it appears to be a combination of hydrogen bonding and electrostatic adsorption. (6) Although silica becomes a major component of the scale after the first steam separation, no organic additive has been found that unequivocally reduces the rate of scale formation above $\sim 160^\circ\text{C}$. Brine acidification remains as the only effective treatment at high temperatures.

Cost of the chemical additive is still a very important parameter to be considered. The organic compounds that appear to be promising at this time are prohibitively expensive. However, our experiments suggest that a mixture consisting of moderate amounts of both a silica colloid stabilizer and hydrochloric acid could be optimized with respect to total cost, scale inhibition, and tolerable corrosion rate. A third beneficial component in a hypothetical antiscalant formulation would be an inhibitor of crystalline scales such as a phosphonate, because there is evidence that compounds such as CaCO_3 aid in nucleating the colloidal silica. Combinations of various components that are potentially synergistic need to be thoroughly investigated.

Further progress in developing chemical treatment of the high-silica brines as a practical technique of scale control should be possible through the following avenues of research:

- Laboratory studies (possibly using such techniques as laser Raman spectroscopy) of the mechanism of interaction of inhibitors with colloidal silica.
- Laboratory and/or field screening of untested compounds closely related to the proven silica precipitation inhibitors. Many such compounds are already commercially available.
- Field measurements of the growth history of colloidal silica particles (size $< 1 \mu\text{m}$) in geothermal systems, in the absence and presence of inhibitors.
- Field studies of the rate of scale formation as a function of time, temperature, hydrodynamics, and substrate material. Is there an induction period or is the rate constant with time? At what scale thickness does the effect of substrate corrosion become negligible? These studies should include high magnification microscopic examination of the scale, and correlation of morphology with conditions of formation.
- Laboratory studies of the effect of precipitation of hydrated species of Fe(II) and other compounds such as CaCO_3 on the nucleation and growth of colloidal silica.
- Examination of the design of the geothermal energy conversion system in the light of the best use of the technique of chemical brine treatment. Study of flow patterns, residence times, and points of injection of additive to optimize the overall effect of scale abatement.
- Investigation of other approaches to scale control such as homogeneous precipitation of silica by increasing the pH of the brine, and seeding the brine with pure, submicron particles of silica.

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